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More Custom-Built Nursery Equipment

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This article describes nursery equipment and gives addresses for ordering construction drawings. Tree Planters' Notes 38(3): 3-6; 1987.

In 1981 I wrote an article describing the wide variety of custom-built equipment nursery people have designed and built over the years to meet their specific needs ("Drawings for Custom-built Nursery Equipment," summer 1981).

The Missoula Equipment Development Center prepared construction drawings of the equipment nursery managers believed would be of most interest and use to their colleagues around the country. These drawings were reproduced and made available to any nursery requesting them. The result was an extensive exchange of equipment ideas that helped solve some nursery equipment problems.

In the 5½ years since that article appeared, much new equipment has been developed by these practical and resourceful nursery people. And again, the Center has prepared construction drawings of much of this new equipment. This article describes both these new drawings and the ones listed in the 1981 article.

The drawings contain enough detail to build the equipment and are available in either reduced size for general use or full size for shop use. All drawings should be ordered directly from individual nurseries unless otherwise indicated.

W.W. Ashe Nursery

WWA-1 mulch spreader. This is a manure spreader modified for applying dry organic mulch. Sheet metal deflectors and belt skirts direct the mulch down onto the nursery bed.

WWA-2 tarp roller. This portable machine, powered by a gasoline engine, rolls up the plastic that covers the seedbed during fumigation.

To order drawings, write:

W.W. Ashe Nursery
Route 1, Box 181B
Brooklyn, MS 39425
Telephone: (601) 584-8488
FTS : 497-4218

Coeur d'Alene Nursery

CDN-1 nursery path cultivator. The nursery path cultivator is a PTO-driven rotary tiller that mounts on a three-point hitch. The blades till the soil in the paths between the beds.

CDN-2 box storage rack and conveyor. The box storage rack and conveyor attaches to a Grayco lifter. Nursery workers take boxes from the rack, fill them with seedlings, roll them down the conveyor, and unload the full boxes onto the ground or into a truck.

CDN-3 dewinger. The dewinger has five rows of rubber fingers that revolve on a shaft within a drum. The revolving fingers remove the light wings from seed and an exhaust fan sucks the wings out of the drum. The seed go through the drum and drop through the bottom of the separator.

CDN-4 sander. The sander is a sifting screen mounted over a hopper that attaches to a fertilizer spreader for spreading a thin layer of sand over the seedbed.

CDN-5 watering boom. The watering boom hangs from an overhead rail in a greenhouse and can be moved along the rail to water seedlings.

CDN-6 container washer. This washer steam-cleans used containers. The containers pass through a washer box on a conveyor belt.

CDN-7 vertical root pruner. The root pruner consists of two gangs of coulter disks that mount underneath a tractor. Hydraulic cylinders raise and lower the disks.

CDN-8 cone tumbler. This equipment tumbles small amounts of tree cones to extract seeds, which are caught in a seed pan. A ? -horsepower motor powers the tumbler. The tumbler is 32 inches in diameter by 32 inches long.

CDN-9 tarp roller. This tractor-mounted implement rolls up plastic tarps that cover the seedbed during fumigation. It mounts on a tractor three-point hitch and is powered from the tractor hydraulics.

To order drawings, write:

Coeur d'Alene Nursery
3600 Nursery Rd.
Coeur d'Alene, ID 83814
Telephone: (208) 765-7375
FTS: 442-7587

Hammermill Paper Co.

HPC-1 seedling top pruner. This three-point-hitch-mounted implement uses a spinning cable drum to top-prune tree seedlings.

To order drawing, write:

Hammermill Paper Co.
Southern Forest Products
Division
417 Medical Parkway Center
Selma, AL 36701
Telephone: (205) 872-5452

Humboldt Nursery

HN-1 tub washer. This is a device for washing seedling tubs by passing them through a high-pressure water spray system.

HN-2 bag washer. This equipment facilitates the washing of standard 18- by 36-inch burlap bags.

HN-3 plastic tarp roller. This tractor-mounted implement is hydraulic powered and is used to pick up tarps used during fumigation. Mounting can be either on a three-point hitch or a front-end loader.

To obtain drawings, write:

Humboldt Nursery
4886 Cottage Grove Ave.
McKinleyville, CA 95521
Telephone: (707) 839-3256

Lucky Peak Forest Tree Nursery

LPN-1 seedling packing carousel. The seedling packing carousel is a round table that is rotated manually. It has special holders for bags, boxes, and paper.

LPN-2 seedling storage and hauling trailer. The box on this single-axle trailer is 10 feet long, 5 feet wide, and 6 feet tall. Snow is packed into the front part of the Styrofoam-insulated trailer to keep the seedlings cool.

LPN-3 irrigation pipe hauling rack. These racks bolt to the front of a tractor and mount on the three-point hitch in back. The racks carry long pipe sections.

LPN-4 seedling hauling trailer. The flatbed of this tandem-axle trailer measures 14 feet long by 7 feet wide. It is used to haul seedlings from the field to the packing shed.

LPN-5 root cutoff saw. The saw prunes seedling roots before packaging. It mounts on the packing belt at the discharge end.

LPN-6 vertical root pruner. This pruner cuts the lateral roots of seedlings in the nursery bed. It is similar to the Coeur d'Alene vertical root pruner.

To order drawings, write:

Lucky Peak Forest Tree Nursery
HC 33, Box 1085
Boise, ID 83701
Telephone: (208) 343-1977

Missoula Equipment Development Center

MEDC-303 cone inspection table. This tilting and vibrating table has a screen and platform useful for inspecting cones at the collection site.

MEDC-427 nursery cultivator. A modified rotary tiller equipped with several chain-driven tiller blades is used to cultivate in between nursery bed rows.

MEDC-517 horizontal root pruner. This pruner is a PTO-driven reciprocating blade that slices underneath the nursery bed. A sturdy frame mounted on a three-point hitch supports the mechanism.

MEDC-606 tree seed dewinger. This dewinger uses rubber flaps that revolve on a shaft within a plastic drum. It features a vibrating feed tray, an adjustable tilt mechanism for the drum, a variable speed electric drive, and a dust control device.

MEDC-684 synchronized thinner. This is a belly-mounted hydraulic-powered tractor implement used in thinning tree seedlings in nursery beds. Some parts are from a John Deere model 200 synchronous thinner.

MEDC-687 manual seedling thinner. This is a two-person, hand-operated device used to thin overstocked tree nursery beds.

MEDC-695 mycorrhizae applicator. This implement mounts on the front of a standard Ojyord/Love eight-row seeder. The applicator places mycorrhizae in nurserybeds during the seeding operation.

MEDC-748 MEDC tree seed dewinger M-1984. This is an updated design of the MEDC-606 tree seed dewinger. This model features easily removable drums.

MEDC-761 hand stake driver. This is a slide-hammer apparatus for hand-driving 18-inch surveyor stakes.

MEDC-795 hydraulic stake driver. This system mounts on a three-point hitch and is powered by the prime mover's hydraulics. The system is used to drive 18-inch stakes in nursery paths to support bird protection netting.

To order drawings, write:

Missoula Equipment
Development Center
Bldg. 1, Fort Missoula
Missoula, MT 59801
Telephone: (406) 329-3958
FTS:585-3958

Mount Sopris Nursery

MSN-1 container filler. This is an inexpensive container filler that is relatively easy to build.

To order drawings, write the Missoula Equipment Development Center at the address above.

Rocky Mountain Forest and Range Experiment Station

RMF&R-1 rolling cart bench. The bench rolls on tracks to move seedlings in a shadehouse.

Write the Missoula Equipment Development Center for this drawing.

Saratoga Tree Nursery

STN-1 Evans weeding cart. This two-seat, lightweight, four-wheeled cart carries two weeders directly over the nursery bed for easy weeding. The weeders move the cart manually.

To order drawings, write:

Saratoga Tree Nursery
R. D. 5, Rt. 50
Saratoga Springs, NY 12866
Telephone: (518) 885-5308

Southern Forest Experiment Station

SEES-1 herbicide applicator. This is a wiper-type herbicide applicator for weed control between rows of trees in nursery beds. The applicator attaches to the three-point hitch of a tractor.

SFES-2 ultimate Stoneville applicator. This wiper-type herbicide applicator mounts on the front of a tractor and is more than 11 feet wide.

To order drawings, write:

Southern Forest Experiment
Station
P.O. Box 227
Stoneville, MS 38776
Telephone: (601) 686-7218
FTS : 497-2404

Southwestern Region (Forest Service)

SWR-1 hectoliter boxes. The boxes are used to accurately measure amounts of cones collected in the field. They are plywood and hold either 1 or 3 hectoliters of cones.

To order drawings, write:

USDA Forest Service
Southwestern Region
517 Gold Ave. SW
Albuquerque, NM 87102
Telephone: (505) 766-2801
FTS : 474-2802

Wind River Nursery

WRN-1 seed rack. This movable rack holds two stacks of 10 trays each. The shallow trays have screen bottoms and hold the seed to be dried.

WRN-2 shade screen. Shadecloth wire stretched within a sturdy frame forms a screen that shelters shade-tolerant seedlings.

WRN-3 pruning saw guard arm. This steel guard covers the pruning saw used on the packing belt for trimming seedling roots.

To order drawings, write:

Wind River Nursery
M.P. 1. 46 R Hemlock Rd.
Carson, WA 98610
Telephone:(509) 427-5679

For further information about nursery and greenhouse drawings, contact Ben Lowman at the Missoula Equipment Development Center.

Freezer Storage Practices at Weyerhaeuser Nurseries

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The storage of conifer seedlings in freezer units at a temperature of -2 °C has become a matter of routine practice at Weyerhaeuser forest nurseries in Washington and Oregon. The evolution of this practice at Weyerhaeuser and current operating procedures are described in this paper. Tree Planters' Notes 38(3) : 7-10; 1987

Need for Long-Term Seedling Storage

The need for long-term storage of seedlings in our Washington and Oregon operating areas exists for a number of reasons. Our nursery facilities west of the Cascade Range are situated at low elevations, less than 1,000 feet. At these nurseries, seedlings must be lifted between December and early March in order to take full advantage of their frost hardiness and root regeneration potential. Because some of our planting sites at higher elevations are not accessible until May or June, storage periods of 2 to 6 months are common.

For our nursery in the Klamath Basin east of the Cascades, situated at 4,000 feet elevation, spring lifting is often confined to 4 to 6 weeks duration because of winter freeze-up and late thaw conditions. Long-term freezer storage allows lifting during late autumn and shipping the following spring. This provides for a more balanced work load, split between the fall and spring, and enables shipping to planting sites that thaw earlier than the nursery during the spring.

It has been our experience that shipping orders from the field can vary widely depending on weather conditions and crew logistics. We attempt to operate our nursery lift and pack operations on a production flow basis and find that freezer storage provides us with such options as lifting in advance of orders and packing seedlings for transplanting when there is slack in outplant orders. Thus, the freezer provides us with an effective surge buffer between nursery and field production.

Development and Testing

During the early and middle 1970's, most of the long-term storage needs at Weyerhaeuser were met using conventional cold storage methods in which storage temperatures are kept at +1 to +2 °C and relative humidity levels of 85 percent or higher. Although these conditions held seedlings satisfactorily for the most part, we did experience some problems with storage molds and fungi. Naturally, the more mud and dirt included in the packing bags, the larger the problem with storage fungi. In an effort to eliminate this problem, in 1976 we decided to explore the alternative of storing seedlings at a temperature just below freezing, -1 to -2 °C.

In 1977, we lifted various lots of seedlings grown from coastal and cascade sources during mid-January, divided these into two groups, and placed one group into the freezer for storage at -2 °C and the other into the cooler at +2 °C (1). Coastal lots were in storage for 6 weeks and cascade lots were stored for 6 months.

At the end of the storage period, the coastal lots were outplanted at a site in our Twin Harbors Tree Farm and the cascade lots were outplanted at our Vail Tree Farm. In the Twin Harbors

Table 1—*Percentage survival of seedlings from a cascade source stored in the cooler (+2 °C) or the freezer (−2 °C) for 6 months and then outplanted at the Vail Tree Farm in 1977*

	North aspect				South aspect			
Species class	Cooler		Freezer		Cooler		Freezer	
Douglas-fir / 2 + 0	85	(5)	90	(3)	23	(8)	15	(5)
Douglas-fir / plug	94	(2)	91	(4)	40	(1)	31	(8)
Western hemlock / 1 + 1	50	(3)	53	(4)	2	(2)	3	(2)

Standard errors shown in parentheses.

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[1] Originally presented at a meeting of the Western Forest Nursery Council, held on August 12-15, 1986, at Olympia, WA.

test, 100 percent of both freezer-stored and cooler-stored lots survived. In the Vail test, no significantly different survival rates were observed between cooler storage and freezer storage for like seedlots (table 1).

Similar tests were conducted with ponderosa and lodgepole pine at Klamath in 1978 comparing freezer-stored with cooler-stored seedlings (2). Seedlings were lifted in mid-October, stored overwinter, then outplanted in late April at Buck Mountain and mid-May at Coyote Creek. Survival percentages (table 2) indicate no significant differences in performance between freezer and cooler storage for either species.

A year later, additional tests were performed with lots of coastal and cascade Douglas-fir, noble fir, and western hemlock seedlings. These were lifted in mid-January at our Mima Nursery and stored in the freezer for intervals of 0, 2, 4, and 6 months. After the designated storage period, these seedlings were outplanted in a research test area at the nursery except for the 6-month lot. These seedlings were potted and evaluated in the greenhouse because by planting time (mid-July) the soil in the research test area had become excessively dry. The results of this test showed no significant decrease in survival percentages with time in freezer storage up to 6 months (table 3). This applied across all three species tested.

Table 2—*Percentage survival of pine seedlings stored overwinter in the cooler (+2 °C) or the freezer (−2 °C) and then outplanted at the Klamath Tree Farm in 1978*

Species	Cooler		Freezer	
Ponderosa pine	87	(8)	84	(10)
Lodgepole pine	88	(10)	93	(6)

Standard errors shown in parentheses.

Table 3—*Percentage survival of seedlings lifted in January and then stored for 0 to 6 months in the freezer (−2 °C) and then outplanted at the Mima Nursery in 1978*

Species	Origin	0		2 mon		4 mon		6 mon[a]
Douglas-fir	Cascade	100	(0)	100	(0)	100	(0)	95
Douglas-fir	Coastal	100	(0)	100	(0)	99	(2)	100
Noble fir	Cascade	98	(4)	99	(2)	86	(7)	100
Western hemlock	Cascade	78	(16)	100	(0)	95	(5)	100

Standard errors shown in parentheses.

[a] Plants were potted and evaluated in a greenhouse because of the excessive dryness of the soil in the test plot.

Test 4—*Survival results for various packing bag treatments*

Bag treatment	Percent survival	S.E.
50#WS + 10#PE/50#WS/50#WS	97	(1)
50#WS + 10#PE/50#WS/50#WS + waxed seam	94	(3)
50#WS + 10#PE/50#WS/50#WS + liner	97	(2)
50#WS + 10#PE/50#WS/50#WS + waxed seam + liner	94	(1)

Initially, we were somewhat concerned over how seedlings for the freezer should be packaged. We knew that the freezer could desiccate the seedlings if the moisture barrier provided by the packaging was not adequate.

Therefore, we experimented with a number of different options (1): a) the standard ply kraft bag (50#WS+10#PE/50#WS/ 50#WS); b) the standard bag with its seam waxed dipped (50#WS+10#PE/ 50#WS/50#WS + liner); c) and the standard bag with the wax-dipped seam plus the poly liner (50#WS+10 #PE/50#WS/50#WS + waxed seam + liner). Acceptable results were obtained with all treatments and the additional safeguards of the wax-dipped seam of poly liner were not justified (table 4).

Table 5 -Some of the species that have been successfully stored in the freezer

Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Noble fir	*Abies procera* Rehd.
White fir	*A. concolor* (Gord. & Glend.) Lindl. ex Hildebr.
Shasta red fir	*A. magnifica* var. *shastensis Lemm.*
Grand fir	*A. grandis (Dougl.* ex D. Don) Lindl.
Balsam fir	*A. balsamea* (L.) Mill
Pacific silver fir	*A. amabilis* Dougl. ex Forbes
Fraser fir	*A. fraseri* (Pursh) Poir.
Western redcedar	*Thuga plicata* Donn ex D. Don
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Sitka spruce	*Picea sitchensis (Bong.)* Carr.
Engelmann spruce	*P. engelmannii Parry* ex Engelm.
Norway spruce	*P. abies* (L.) Karst.
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
Lodgepole pine	*P. contorta Dougl.* ex Loud.
Scotch pine	*P. sylvestris* L.
Western white pine	*P. monticola* Dougl. ex D. Don
Eastern white pine	*P. strobus* L
Western larch	*Larix occidentalis Nutt.*
Giant sequoia	*Sequoiadendron giganteum* (Lindl.) Buchholz
Red alder	*Alnus rubra* Bong.
Quaking aspen	*Populus tremuloides* Michx.
Oregongrape	*Mahonia aquifolium* Nutt.
Red maple	*Acer rubrum* L.

Current Freezer Storage Practice

The use of freezing temperatures for long-term seedling storage has been a routine practice for our nurseries since 1978. We currently store about 25 million seedlings annually in freezers. Over the years we have found that many species can be freeze-stored at -2 °C successfully (table 5).

Some basic elements that are important in the freeze-storing of conifers include physiological condition of the seedlings, packaging, and thawing before planting. As with conventional cold storage, it is always advisable to start with seedlings that are clean, healthy, and disease free. Though most fungi will not grow and spread in freezer storage, they will still be viable when the trees are removed from storage for thawing and planting.

Seedlings should be exposed to the natural chilling conditions that occur in autumn in order to promote dormancy and frost hardiness. In our nurseries west of the Cascades, we find that by the first to second week in December virtually all seedlings are hardy to -5 °C and LT_{50}'s of -10 °C are not uncommon. At our Klamath nursery these conditions will occur at least a month earlier. Once seedlings attain these levels of hardiness they will store well under freezing conditions at -2 °C.

The freezer storage facilities that we use are simply conventional refrigerator units operated at -1 to -2 °C. There are no provisions in these units for humidity control, and because the evaporators are placed directly in the storage areas themselves, the humidity is quite low. It is therefore important to provide a moisture barrier in the packaging of the seedlings. Storage of seedlings in exposed bales will not work, for the seedlings will desiccate.

We pack seedlings in both bags and boxes depending on customer preference. The bags are standard kraft seedling bags, which are widely used by Washington and Oregon forest nurseries. These bags are of 3-ply construction with the inner ply treated with a 10# polyethylene spray coating. This coating provides a suitable moisture barrier.

Seedlings are packed in the bags in a moist (not waterlogged) condition, and the bag is sealed by folding and rolling the top down. The application of two or three straps secures each package. The packages are then placed on pallets with racks that allow for stacking and the entire palletized stack is moved directly into the freezer.

In the case of boxes, we use a 1.5-mil poly liner placed inside the box to prevent loss of moisture. The liner is sealed by twisting and tucking and is held secure by the top flap. Once palletized, the boxes of seedlings are moved directly to the freezer.

Whatever is used to package the seedlings must provide a seal against moisture loss and be durable enough to withstand normal impact and abrasion in the production operation without sustaining tears and punctures. Should a bag or box be punctured, it can be patched with tape if a wax-coated surface is not involved. Wax surfaces are a challenge to repair.

Freezer temperatures should be checked daily and maintained at -1 to -2 °C. A continuous measuring device such as a thermograph is recommended as it provides the operator with a permanent record of temperature over time. Once in the freezer, seedlings may take up to 10 days before they freeze solid. Plug seedlings will take longer than bareroot seedlings because of the potting soil and additional moisture contained in the root plug. Seedlings handled and packed in the manner described will keep well up to 6 months in the freezer.

Seedlings must be thawed before they are planted, for frozen root systems or stems can cause transpirational drought stress. We thaw seedlings at the nursery before they are shipped to the customer. Thawing is done in a warehouse or similar structure at ambient temperature (+10 to +15 °C). The pallets are spread out to allow for ample air circulation between pallet stacks.

Bareroot seedlings normally take 3 to 5 days for thawing whereas plug seedlings will require 10 to 15 days. Once thawed, the seedlings can be shipped to the customer for planting. It is preferable to plant seedlings as soon as they have thawed; however, our experience shows that they can be held in cooler storage after thawing up to 4 weeks without detriment.

Summary

Storing seedlings at -2 °C is a practical and proven means of holding conifers in a dormant, viable condition for periods up to 6 months before planting. Though cooler storage at +2 °C can provide similar results, the probability of problems with storage molds is much greater. Most western conifers can be freezer-stored provided they are in a dormant and hardy condition before lifting and storing. Packaging seedlings for the freezer must include a moisture barrier. A polyethylene bag placed in the packing box or a polyethylene coating applied to the inner ply of the packing bag served well in this function. Unlike cooler-stored trees, freezer-stored trees require thawing. This step is most practically achieved by simply spacing pallets of seedlings out in a warehouse at +10 to +15 °C.

Literature Cited

1. Gutzwiler, Jerry. Freezer storage of western conifer seedlings. Weyerhaeuser Tech. Rep. Centralia, WA: Weyerhaeuser Forestry Research Center, 1978. 21 p.
2. Stevens, Robert G.; Heninger, Ronald L. Klamath Falls nursery fall lift and overwinter storage: 1977-78, 1978-79, and 1979-80 results. Weyerhaeuser Tech. Rep. Centralia, WA: Weyerhaeuser Forest Research Center. (Unpublished).

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Some Effects of Cold Storage on Seedling Physiology

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*When tree seedlings are lifted from the nursery in winter and placed into cold storage, they are no longer exposed to the natural environmental factors that provide energy for growth and information for phenological development. This affects many important physiological variables that influence seedling quality. This paper summarizes several years of storage physiology research on Douglas-fir (*Pseudotsuga menziesii *(Mirb.) Franco). Stored carbohydrates are depleted, dormancy release is slowed, and cold hardiness is gradually lost in cold storage. Root growth potential may increase, decrease, or remain constant, depending on lift date, storage duration, and species. Effects of cold storage on seedling water relations have not been adequately investigated.* Tree Planters' Notes 38(2):1115; 1987.

Cold or frozen storage enables nursery managers and foresters to hold fall- or winter-lifted nursery stock until spring planting. Because of this, it has become an invaluable tool in forest regeneration operations in the Pacific Northwest.

In the natural outdoor environment, tree seedlings are exposed to strong diurnal fluctuations in air and soil temperature, light intensity and duration, soil and atmospheric water status, and other factors. Over the millennia, tree species have adapted to use these factors as sources of both energy for growth and information for driving phenological development (1).

When seedlings are lifted from the nursery or greenhouse and stored in the cold and dark, they no longer experience these environmental changes. Rather, temperature remains low and constant, light is absent, and humidity is very high.

In this paper, I will discuss some important physiological processes and variables and outline the manner in which they respond to the cold storage environment, based almost entirely on our research and experience with coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings at Weyerhaeuser. When available and pertinent, data from other conifers are also cited. The focus of the review is on seedling quality.

Physiological Variables Affected

Innumerable physiological processes and variables affect seedling physiological quality. Among the variables strongly affected by cold storage are: (1) carbohydrate reserves, (2) bud dormancy status, (3) root growth potential, (4) cold hardiness, and (5) water relations.

Carbohydrate reserves. Nearly all plant food reserves are stored in the form of starch and sugars. These are produced ultimately by photosynthesis and are consumed by respiration to sustain plant growth and metabolism. Both photosynthesis and respiration are strongly temperature-dependent, and photosynthesis requires light.

Cold storage affects photosynthesis and respiration in two ways. First, the absence of light stops photosynthesis and second, low temperature decreases the rate of respiration. The net effect is that seedlings burn up their supply of reserve carbohydrates in storage, but they do so very slowly.

In an experiment with 2+0 Douglas-fir, total nonstructural carbohydrate (TNC) concentrations in January were highest in foliage (4). During the first 2 months of storage, foliar TNC was respired more rapidly than stem or root TNC (fig. 1). During the following 20 months, a near-linear decrease in TNC occurred in all tissues, the result being that during 1 year the seedlings had consumed roughly half their food reserves. Storage temperature also affects the rate of loss of food reserves. Douglas-fir

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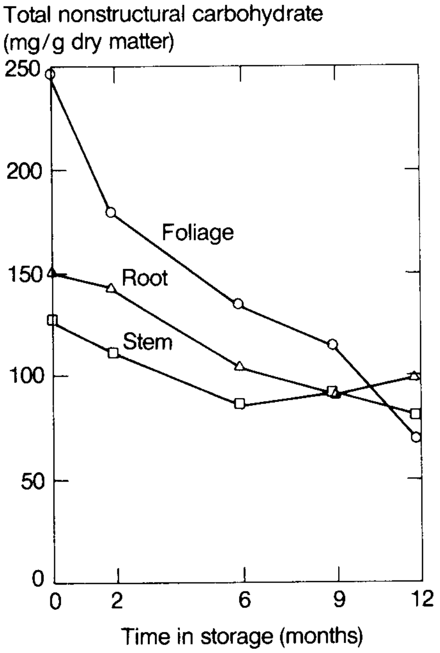
seedlings stored at -2 °C contained about 2.5 milligrams per gram more TNC after 6 months than did those stored at +2 °C (Ritchie, unpublished data).

It would be valuable to know how much food reserve is necessary to ensure survival and adequate early growth, but this information is not yet available. As a first approximation, 10 to 12 milligrams per gram might be a reasonable estimate.

Bud dormancy status. By late fall (October) in the coastal Pacific Northwest, conifer seedlings normally will have reached the peak of dormancy (3). As winter progresses, continual exposure to temperatures below about 6 °C (chilling) acts to release dormancy. By March, dormancy release is complete and seedlings will break bud and begin growing upon exposure to warm, springlike conditions.

This progress through dormancy to dormancy release can be visualized by plotting a dormancy release index (DRI) curve over the accumulation of hours of chilling temperatures. DRI for Douglas-fir is calculated as the number of days to terminal budbreak of seedlings held in a warm, forcing environment (DBB) divided into 10 (5). As dormancy release progresses through winter the DRI value approaches unity. This relationship is shown for 2+0 Douglas-fir seedlings of four seed zones in figure 2.



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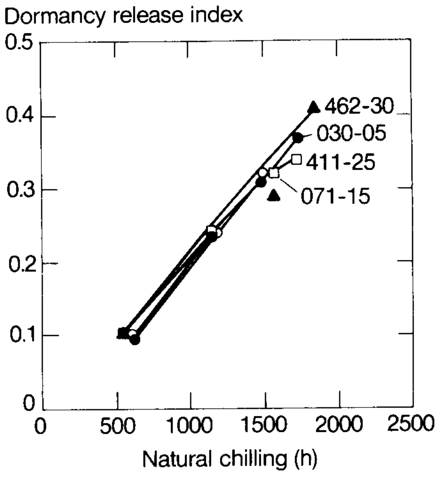

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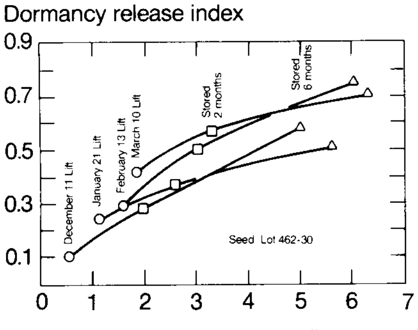
Figure 1—*Changes in total nonstructural carbohydrate concentrations in foliage, stems, and roots of 2+0 Douglas-fir seedlings lifted January 27, 1978, and stored at −1 °C. Vertical bars ± 1 standard error. Reproduced with permission from Canadian Journal of Forest Research 12(4):908; 1982.*

Figure 2—*Dormancy release index in 2+0 Douglas-fir seedlings as a function of natural (nursery) chilling. Data are for the winter of 1979–80. Each point is a mean (± standard error) of 15 seedlings held in a forcing environment. A chilling hour is defined as one during which the air temperature is below 6 °C. Reproduced with permission from Canadian Journal of Forest Research 14(2):188; 1984.*

When seedlings are lifted from the nursery and placed into cold storage, several things occur that affect this relationship. First, seedlings are no longer exposed to daily fluctuating light and temperature; and second, they are held at a temperature that is apparently not very efficient at releasing dormancy. The net effect is that dormancy release does occur-but at a much reduced rate.

In the experiment illustrated in figure 3, we lifted Douglas-fir seedlings on four dates during winter and determined their DRI values. (These are plotted as circles on the figure.) We then held back samples of these seedlings



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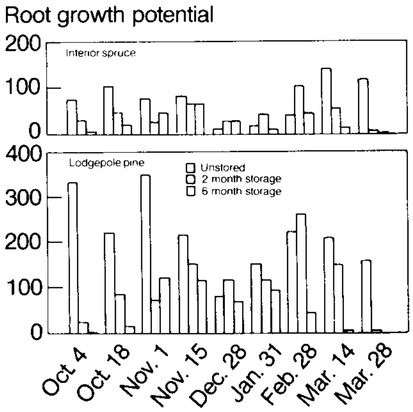

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Figure 3—*Dormancy release index in 2 + 0 Douglas-fir seedlings from a seed zone in the western Oregon Cascades during winter of 1979–80. Seedlings were lifted at one of four times during winter and stored at − 1 °C for 2 or 6 months. Chilling sum is the sum of nursery chilling and hours held in storage. Reproduced with permission from Canadian Journal of Forest Research 14(2):188; 1984.*

Figure 4—*Root growth potential (number of new roots per seedling) of 2 + 0 lodgepole pine and interior spruce seedlings lifted throughout winter from a central British Columbia nursery. Seedlings were tested immediately after lifting and after 2 and 6 months in − 1 °C storage. Each value is a mean (± standard error) of 20 seedlings. Reproduced with permission from Canadian Journal of Forest Research 15(4):639, 1985.*

for storage at -1 °C for 2 (squares) and 6 (triangles) months, then removed them and again determined the DRI values. In each case, seedlings were far more dormant after storage than they would have been had they been allowed to remain in the nursery beds. Similar experiments were performed with lodgepole pine (*Pinus contorta* Dougl. ex Loud.), and interior spruce (*Pinus glauca-englemannii* complex) with similar results (7), suggesting that this may be a relatively common response in many conifers.

The practical implication of this phenomenon is that one can lift stock in fall or winter when it is dormant and hold it in a dormant condition well into spring for spring planting. It is primarily because of this relationship that cold storage works as well as it does.

Root growth potential. Root growth potential (RGP) is not a physiological process per se. However, it integrates many important physiological processes in the seedling and, for this reason, has become a popular and useful indicator of seedling vigor. The rationale is that if there is any problem with the seedling physiologically, it should show up as a decrease in the seedling's ability to produce roots.

Root growth potential is strongly affected by cold storage. In 2+0 Douglas-fir a very clear pattern has emerged over several seasons of testing. Root growth potential is low in fall and early winter, increases and peaks in December and January, then decreases in February to a low in March. With respect to cold storage: 2 months of storage is nearly always beneficial, the greatest benefit being gained with stock lifted in fall and early winter; while 6 months of storage is rarely beneficial, especially when stock is lifted in late winter or spring.

This relationship is apparently not universal, however. In a study with lodgepole pine and interior spruce (7) quite different patterns were observed (fig. 4). The reasons for these differences are not known and until the underlying mechanisms driving RGP are understood it will probably be necessary to develop this information for each species and, perhaps, each nursery as well.

Cold hardiness. A seedling's ability to endure subfreezing temperatures varies dramatically over the course of the year. In summer, exposures to -5 °C are sufficient to kill Douglas-fir seedlings. But in mid-winter these same seedlings can easily withstand temperatures below -20 °C. Hardier northern species such as white spruce (*Picea glauca* (Moench.) Voss) and lodgepole pine can withstand midwinter temperatures approaching -80 °C.

Hardiness develops in fall in response first to shortening photoperiod then to increasing exposure to cold nights (2). As nights become increasingly colder, seedlings become more and more hardy. Increasing photoperiod and higher temperatures in spring cause seedlings to lose hardiness rapidly. This is why late frosts can be so damaging.

One would suspect that removal of a seedling from these environmental signals by placing it in cold storage would interfere with the development of natural hardiness. Further, because carbohydrate reserves undergo a net loss during storage and hardiness development requires an expenditure of metabolic energy, one would expect a loss of hardiness with time in storage.

Unfortunately, very little information exists on the effect of cold storage on hardiness in tree seedlings. However, the limited data that do exist (table 1) tend to confirm the above predictions. Pine and spruce seedlings lifted early in winter while hardiness was developing did not continue to harden in storage, rather they slowly lost hardiness. Seedlings lifted in spring continued to deharden in storage.

Table 1—*Estimated values of lethal temperatures for 50 percent of the test population (LT_{50}, in °C) for lodgepole pine and interior spruce seedlings at time of lifting and after 2 or 6 months in storage at −1° C*

Lifting date storage period	Treatment date	Lodgepole pine	Interior spruce
October 4, 1982			
0	October 4, 1982	(−20)	(−26)
2 mon	December 4, 1982	(−14)	−27
6 mon	April 4, 1983	—	−14
November 1, 1982			
0	November 1, 1982	−29	−30
2 mon	January 1, 1983	−26	−26
6 mon	May 1, 1983	−20	−25
March 28, 1983			
0	March 28, 1983	−18	−18
2 mon	May 28, 1983	(−11)	−18
6 mon	September 28, 1983	−7	−18

Values in parentheses are extrapolations, the remaining values are interpolations of percent injury over temperature curves from whole-plant freeze tests.

Taken from Canadian Journal of Forest Research 15(4):640, 1985.

More research is needed on this question, for it has important implications. Suppose, for example, that seedlings are lifted in the fall for planting in midwinter. If they have not developed adequate hardiness before lifting and are planted on a very cold site, they might suffer considerable winter damage. One wonders how much overwinter damage can be attributed to this cause. On the other hand, seedlings that are lifted in winter can be held well into spring for planting at high elevations where exposure to low temperatures is expected. In the table 1 data, for instance, seedlings lifted in November were still hardy to -20 or -25 °C when tested the following May.

Water relations. Seedling water relations are very complex, and a complete discussion is far beyond the scope of this paper. Suffice it to say that during mid-winter conifers exhibit very "favorable" water relations properties, that is, they are able to tolerate substantial desiccation of both tops and root systems without incurring appreciable damage (6,8).

By spring (March) when growth begins, water relations properties shift abruptly to a far less favorable status and seedlings become very sensitive to water-related stresses. The success of the mid-winter lifting window may be due in part to these highly favorable seedling water properties.

The question is: what effect does storage have on seedling water status? Do seedlings maintain favorable water status in storage or does water status deteriorate? Unfortunately this question has not been studied. One might speculate, however, that because carbohydrates are depleted in storage, and because water relations reflect osmotic relations that depend to a degree on dissolved carbohydrates in the cells, we would see a gradual deterioration of seedling water status with time in cold storage. This might partially explain why storage beyond 6 to 9 months almost invariably results in poor performance of planting stock. This is an interesting and important question and deserves to be investigated.

Summary and Conclusion

When tree seedlings are held in cold, dark storage for prolonged periods of time, they are separated from the sources of environmental energy and information they need to develop in synchrony with the changing seasons. This affects many important physiological processes and variables. Effects of cold storage on dormancy release, carbohydrate depletion, and root growth potential have been studied and are reasonably well understood at least in an empirical sense. Effects on some other important variables such as cold hardiness and water relations are less well known.. On balance, positive effects of cold storage heavily outweigh negative effects, hence it has become a widespread and very useful practice throughout most of the Pacific Northwest.

Literature Cited

1. Campbell, R.K. Regulation of budburst timing by temperature and photoregime during dormancy. In: Hollis, C.A.; Squillace, A.E., eds. Proceedings, Fifth North American Forest Biology Workshop, 1977. Gainesville: University of Florida, School of Forest Resources and Conservation; 1978.
2. Glerum, C. Frost hardiness of coniferous seedlings: principles and applications. In: Workshop proceedings, Evaluating seedling quality: principles, procedures, and predictive abilities of major tests; 1984 October 16-18, Corvallis, OR. Corvallis: Oregon State University, Forest Research Laboratory; 1985: 107-123.
3. Lavender, D.P. Bud dormancy. In: Workshop proceedings, Evaluating seedling quality: principles, procedures, and predictive abilities of major tests; 1984 October 1618; Corvallis, OR. Corvallis: Oregon State University, Forest Research Laboratory; 1985: 7-15.
4. Ritchie, G.A. Carbohydrate reserves and root growth potential in Douglasfir seedlings before and after cold storage. Canadian Journal of Forest Research 12:905-912; 1982.
5. Ritchie, G.A. Effect of freezer storage on bud dormancy release in Douglasfir seedlings. Canadian Journal of Forest Research. 14:186-190; 1984.
6. Ritchie, G.A. Relationships among bud dormancy status, cold hardiness, and stress resistance in 2+0 Douglasfir. New Forests 1:29-42, 1986.
7. Ritchie, G.A.; Roden, J.R.; Kleyn, N. Physiological quality of lodgepole pine and interior spruce: effects of lift date and duration of freezer storage. Canadian Journal of Forest Research 15:636-645; 1985.
8. Ritchie, G.A.; Shula, R.G. Seasonal changes of tissue-water relations in shoots and root systems of Douglas-fir seedlings. Forest Science. 2:538-548; 1984.

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A Simple Method for Evaluating Whole-Plant Cold Hardiness

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Whole-plant assessment is direct, requires a minimum of equipment and expertise, and provides a good approximation of actual cold hardiness. Potted test plants are subjected to several target temperatures in a slightly modified domestic chest freezer. After gradual warmup, the plants are placed in a favorable growing environment for 7 to 14 days, and then the percent of cambial damage is determined. The temperature at which 50 percent damage occurs is determined graphically. Tree Planter's Notes 38(2):16-18; 1987.

To produce high-quality, properly hardened nursery stock in greenhouses and out-of-doors, it is essential to a) understand the cold hardening process, and b) test for cold hardiness as a guide for manipulating nursery and greenhouse environments. Basically, the objective of cold hardiness testing is to verify that the cultural treatments being applied are producing the desired results. Choosing an appropriate method to test for cold hardiness can be an overwhelming task because of the many testing methods used in research (1, 3, 4).

In this paper, we describe a simple whole-plant assessment method that is suitable for both production nurseries and comparative research studies. Testing intact plants approximates actual cold hardiness and predicts plant survival better than does testing excised tissue samples. The method requires a minimum of equipment and skill, the procedure is simple, and the results can be correctly interpreted without calibration. However, a longer waiting period is required before the extent of damage can be measured.

Briefly, the whole-plant method consists of a) placing potted test plants in a chest freezer with roots insulated in a bed of vermiculite; b) lowering the temperature until target temperatures are reached, then removing seedlings from the freezer; c) after gradual warmup, placing the seedlings in a favorable growing environment for 7 to 14 days; d) determining the extent of cambial damage; and e) plotting the data and interpolating the temperature at which 50 percent damage occurs.

Equipment

The test is conducted in a domestic chest freezer that can attain temperatures of -25 to -30 °C. A thermometer with remote readout is used so that temperatures in the chest can be monitored without opening the lid. A 50 cubic feet per minute fan is used to circulate the air within the freezer. The fan should be less than 15 watts to avoid unnecessary heat load within the chest.

A cold room or refrigerator at +1 °C is ideal for slowly thawing the seedlings. If neither is available, a Styrofoam cooler will do. A greenhouse is best for allowing injury symptoms to develop, but a warm well-lighted room will suffice.

Conducting the Freezing Test

The plants to be tested are potted with roots in moist growing medium. Styrofoam containers work well because they help insulate the roots. The number of seedlings per container is not important as long as their crowns are well spaced for adequate air circulation.

The objective is to choose target temperatures that bracket the killing temperature. A wrong estimate may leave the killing temperature off the scale of the test, in which case a second test must be run. We recommend at least three target temperatures, each represented by 10 plants. Before a test begins, randomly divide the plants among the target temperatures and give them color-coded labels to facilitate their removal.

Set the containerized plants in the bottom of the freezer and pour vermiculite around the containers so the pots are covered with 5 centimeters of vermiculite. It is important that the root systems get no colder than -2 °C during the tests (0 °C if the roots are actively growing).

To run the test, turn the freezer and fan on and set the freezer control at its lowest setting. The rate of cooling down to 0 °C is not important, but below that level it should not exceed 2 to 6 °C per hour. At 0 to -10 °C, cooling may be too fast, but can be reduced by inserting a small wedge (such as a pencil) under the chest lid to hold it open slightly.

When the first target temperature is reached, turn the fan off, then open the freezer and quickly remove the designated plants and place them in a cold room or in a Styrofoam cooler containing ice. Then repeat this procedure with the remaining target temperatures.

The rate of thawing can be much faster than the rate of freezing, up to 20 °C per hour. An overnight thawing period is sufficient. Then move the potted plants to a favorable growing environment and keep them well watered.

Freezing damage to leaves (or needles), buds, and cambium can be assessed separately and combined into a damage scale, but we prefer to measure only cambial damage. Damage symptoms to cambial tissue require 7 to 14 days to develop, depending on species and environment.

To assess damage, use a knife or razor blade and scrape the entire length of the stem down to the cambium. The color of healthy tissue is fresh green, but damaged tissue changes over time from fresh green to drab olive green to brown.

The symptoms of injury will vary from one species to another, and the rate of symptom development will depend on the hardiness of the plants and conditions in the greenhouse or room where the plants are incubated. With plants in early stages of cold acclimation, symptoms will be readily visible after 7 days. Hardy plants take longer. It is usually desirable to estimate damage as soon as possible, but the longer the incubation period, the less the chance of error.

Measure the length (+ 0.5 centimeters) of the damaged stem down from the shoot tip, then measure the total stem length, excluding the 5 centimeters covered with vermiculite. Calculate the percent damage for each plant as: (damaged length per total length) x 100. Determine the mean percent damage for the test plants representing each target temperature. Next, plot percent damage versus temperature (fig. 1). From the graph, determine the temperature at which 50 percent damage would occur; this is the lethal temperature for 50 percent damage, or LT_{50}. Or, you may wish to determine the temperature at which no damage occurs, or 20, 50, or 100 percent damage-depending on your preferences and the purpose of the nursery stock.

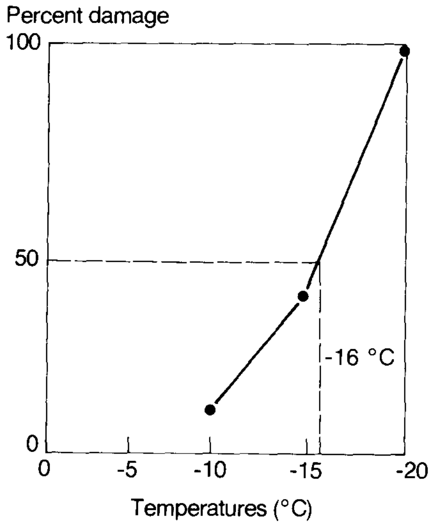

Figure 1—*Percent cambial damage plotted for three freezing test temperatures (−10, −15, and −20 °C), as determined with the whole plant assessment method. The temperature for 50 percent damage (LT_{50}), in this case about −16 °C, is determined from the graph.*

Discussion

A domestic chest freezer has enough cooling capacity for testing during the hardening period to determine if plants have attained sufficient cold hardiness to withstand the natural environment. If you desire additional cooling capacity, replace the refrigerant to extend the lower limit to about -30 °C. Or place a pan of liquid nitrogen in the freezer. Determining the maximum cold tolerance of plant materials requires more sophisticated (and expensive) equipment capable of reaching -70 °C.

Our method assumes that the youngest parts of the seedling are the most vulnerable to freezing injury, so that the severity of injury increases as more of the stem is damaged, from the top down. If the species you are working with shows a different pattern of freezing injury, devise an alternative damage rating scheme.

The amount of damage that occurs in a freezing cycle depends on the low temperature attained, on the rates of freezing and thawing, and on the duration of the low-temperature period. Some authors recommend that each target temperature be maintained for a specified time period (1 to 3 hours) before removing the plants (1). We prefer to remove plants immediately once the target temperature is reached.

A test that requires holding the plants at specified minimum temperatures requires more time and equipment than one in which plants are removed immediately upon reaching a benchmark temperature. Although the results of the two methods may be somewhat different, they are both usable for predicting field reaction to freezing temperatures. The important issue here is to choose a technique, then apply it uniformly and consistently.

If maintaining each target temperature is desirable, you can install a microswitch temperature controller (or for more money, a cam-operated or electronic temperature controller) on the outside of the freezer control at its lowest setting. Then the temperature controller and light bulb, working against the freezer's cooling system, will maintain any desired temperature.

In some freezing tests, the plants are inoculated with ice to minimize the damaging effects of supercooling. Plant tissue supercools if the temperature of the cell solution falls below the freezing point without the formation of ice. When ice does form in supercooled tissues, crystals form very rapidly and are more damaging to tissue than ice that forms slowly in association with little or no supercooling.

Supercooling is of more concern when target temperatures fall in a range of 0 to -5 °C. Wrapping the seedling stems with a 1- to 2-centimeter-wide strip of damp cheesecloth inoculates plants with ice and circumvents supercooling during freezing tests (2). Because our method does not include seeding with ice crystals, supercooling and increased damage may occur. But results of the test are consistent. The cooling rate of 2 to 6 °C per hour should be maintained as uniformly as possible within and between tests.

Literature Cited

1. Glerum, Christiaan. Frost hardiness of coniferous seedlings: principles and applications. In: Duryea, M. L. (ed). Proceedings, Evaluating seedling quality: principles, procedures, and predictive abilities of major tests, 1984 October 16-18; Corvallis, OR. Corvallis: Oregon State University, Forest Research Laboratory; 1985: 107-123.
2. McKenzie, J.S.; Weiser, C. J. Technique to inoculate woody plant stem sections with ice during artificial freezing. Canadian Journal of Plant Science 55:651-653; 1975.
3. Warrington, I. J.; Rook, D.A. Evaluation of techniques used in determining frost tolerance of forest planting stock. New Zealand Journal of Forestry Science 10:116-132; 1980.
4. Yadava, U.L.; Doud, S.L.; Weaver, D.J. Evaluation of different methods to assess cold hardiness of peach trees. Journal of the American Society for Horticultural Science 103:318-321,1978.

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The Effect of Chilling and Seed Source on the Growth of Containerized Fraser Fir (*Abies fraseri* (Pursh) Poir.) Seedlings

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Artificial and natural chilling of containerized Fraser fir (Abies fraseri (Pursh) Poir.) seedlings were compared in seed from two sources. Seedlings from both sources showed superior elongation when chilled outdoors through November 13 than when chilled artificially in a cold room at 2 °C. Height growth of 15-month-old containerized seedlings exceeded that of 4-year-old conventionally grown seedlings. Tree Planters' Notes 38(2):19-21; 1987.

Fraser fir (*Abies fraseri* (Pursh) Poir.) is an important Christmas tree species throughout North Carolina, Tennessee, and Virginia. Commercial plantations are generally established with 5-year-old (3 + 2) transplants (1). As a result of this long production period, demand for seedlings exceeds their supply in most years. This has prompted considerable interest in accelerating growth and increasing the production of plantable Fraser fir seedlings.

Growing containerized seedlings in a greenhouse can significantly reduce seedling production time (3) and may be a feasible method for increasing and accelerating the production of Fraser fir seedlings. However, information dealing with the production of containerized Fraser fir seedlings is limited.

Even under optimum growing conditions and continuous long photoperiods, growth of Fraser fir seedlings is limited because seedlings become dormant after only three to four growth flushes (2). Further exposure to long days results in limited new bud break, and seedlings that do break bud often exhibit stunted, abnormal elongation and loss of apical dominance. A chilling period of 4 to 6 weeks has been found to induce bud break and maximize shoot elongation in Fraser fir seedlings (2).

This study was conducted to evaluate the effects of short periods of cold storage on accelerating and maintaining normal growth of containerized Fraser fir seedlings.

Materials and Methods

Wild seed from two sources (Mt. Rogers, VA, and Roan Mountain, NC) were planted in "Cone-tainer" super cell containers filled with ProMix BX. Seedlings were grown in a greenhouse maintained at a minimum temperature of 15 °C and a maximum of 27 °C. Photoperiod was maintained at 16 hours through the use of incandescent lights. Seedlings were fertilized twice weekly with half-strength Hoagland's solution.

After about 5 months of growth, high greenhouse temperatures in June required moving the seedlings to a slat-house (50 percent shade). No further growth was detected after the seedlings were moved, and they all exhibited well-developed terminal buds. In August, about half of the seedlings were moved into a conventional, dark cold storage facility maintained at 2 °C for 4 weeks, after which they were placed back in a greenhouse. The remaining seedlings were kept outside through November 13, subjecting them to a natural chilling, after which they were placed back in a greenhouse.

Minimum and maximum temperatures from November 1 through November 13 averaged 4.8 °C and 12.7 °C, respectively, with 5 nights below 5 °C. The lowest temperature for this period was 1 °C and the highest 20 °C.

Total seedling height and length of the newest flush was measured after an additional 3 months of growth in a greenhouse. Sample sizes measured varied from 327 seedlings for the artifically chilled seedlings to 463 seedlings for the naturally chilled seedlings. Heights of containerized seedlings were compared against a random sample of conventionally grown seedlings obtained from a commercial nursery.

Results and Discussion

Total height growth of seedlings varied significantly by seed source (table 1). Growth of Mt. Rogers seedlings averaged 13.2 centimeters; Roan Mountain seedlings averaged 11.7 centimeters. Elongation of seedlings following cold storage did not differ between seed sources; both averaged 6.6 centimeters of new growth (table 1). Therefore differences in total height were due to initial growth differences that occurred before chilling. No significant interaction between seed source and chilling treatment was found.

The natural chilling through November 13 resulted in significantly better growth than the artificial chilling at a constant 2 °C in the dark cold room. Growth of naturally chilled seedlings averaged 14.1 centimeters, whereas that of artificially chilled seedlings averaged only 10.1 centimeters (table 1). This difference in total height was due to better elongation in the naturally chilled seedlings, which averaged 8.3 centimeters. Artificially chilled seedlings averaged only 4.1 centimeters in elongation (table 1).

Many of the artificially chilled seedlings exhibited stunted elongation and loss of apical dominance similar to that reported by Hinesley (2). Hinesley (2) found that 4 weeks of chilling at 4 °C was sufficient to overcome abnormal elongation; whereas, in this study 4 weeks at 2 °C failed to provide sufficient chilling for normal elongation.

Table 1—*Total height and elongation after chilling of 15-month-old Fraser fir seedlings as affected by seed source and chilling technique*

	Height (cm)	Elongtion after chilling (cm)
Seed source*		
Mt. Rogers	13.2 a	6.6 a
Roan Mountain	11.7 b	6.6 a
Chilling treatment		
Cold room	10.1 a	4.1 a
Natural	14.1 b	8.3 b

Means followed by the same letter within a row and treatmant do not differ significantly.
*All seedlings in this test were chilled in a cold room at 2°C for 4 weeks.

Table 2—*Height growth of Fraser fir seedlings*

Age	Height growth (cm)
Conventional seedlings	
1 + 0	2.3
3 + 0	7.6
3 + 1	11.5
Container-grown seedlings	
6 months	3.0
9 months	8.8
15 months	14.1

A comparison of conventionally grown seedlings from one North Carolina nursery and containerized seedlings is presented in table 2. Heights of 6-month-old and 9-month-old containerized seedlings are averages from an additional unpublished study. Average height of 6-month-old containerized seedlings exceeds that of a 1 + 0 conventionally grown seedling. At 9 months, containerized seedlings averaged 8.8 centimeters, taller than a 3 + 0 conventionally grown seedling. Naturally chilled 15-month-old containerized seedlings averaged 14.1 centimeters, compared to only 11.5 centimeters for a 3 + 1 conventionally grown seedling, a 23-percent increase (table 2).

Conclusions

Growing Fraser fir seedlings in containers appears to be a feasible method for accelerating their production. Short periods of chilling to break dormancy, followed by further growth in a greenhouse, can produce a seedling in 15 months that is taller than a 4-year-old conventionally grown seedling. For promoting normal elongation, natural chilling outdoors with fluctuating temperatures and natural photoperiod appears to be superior to artificial chilling at a constant temperature in the dark.

Literature Cited

1. Hinesley, L.E. Cold storage of Fraser fir seedlings. Forest Science 28:772-776; 1982.
2. Hinesley, L.E. Dormancy in Abies fraseri seedlings at the end of the first growth cycle. Canadian Journal of Forest Research 12:374-383; 1982.
3. Tinus, R.H., McDonald, S.E. How to grow tree seedlings in containers in greenhouses. Gen. Tech. Rep. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1979.

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Nursery and Field Evaluation of Compost-Grown Conifer Seedlings

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*Three conifer species-Douglas-fir (*Pseudotsuga menziesii *(Mirb.) Franco), noble fir (*Abies procera *Rehd.), and ponderosa pine (*Pinus ponderosa *Dougl. ex Laws.)-were grown in four levels (control, 2, 4, and 6 inches) of composted sludge. Seedlings given the 2- and 4-inch treatments showed the best response after the first year in the nursery. Of the three species, Douglas-fir seedlings responded best. Immobilization of nutrients and heavy metal accumulations resulting from compost application are discussed.* Tree Planters' Notes 38(2):22-27; 1987.

An essential part of forest tree nursery culture is the use of organic amendments. Organic matter maintains soil characteristics such as low bulk density, high water- and nutrient-holding capacities, improved soil structure, and optimal environments for beneficial rhizosphere microorganisms (nitrifying bacteria, mycorrhizae, etc.) (7).

Common organic amendments include green manure from cover crops, sawdust, and peatmoss. Unfortunately, all have a high carbon to nitrogen ratio, may cause net nutrient immobilization, and may release phytotoxic compounds. The availability of sawdust and peatmoss is limited, for they are used in other markets. Cover cropping requires additional nursery acreage.

Composted material derived from manure, sawdust, or spent mushroom compost results in less immobilization and little or no phytotoxic effects while still providing the desired organic input (3). Municipal sewage is an abundantly available organic nutrient source and has been favorably utilized in conifer seedling production (1,4).

Addition of sludge provides supraoptimal nitrogen levels and will increase heavy metal levels in soils and plants (3). However, the use of both sludge and sawdust that have been composted together combines the beneficial characteristics of each and mitigates the less desirable properties.

The purpose of this experiment was to investigate the potential use of a sawdust-sludge compost in forest tree nurseries.

Methods

Nursery. Nursery beds at the USDA Forest Service Wind River Nursery, Carson, WA, were amended with compost (fir-hemlock sawdust municipal sewage sludge, 3:1 from METRO, Seattle, WA). Density = 0.2 grams per cubic centimeter, nitrogen = 0.5 percent; other characteristics are listed in Bledsoe (3).

Each of 12 nursery beds (330 feet long) were randomly selected for a particular compost treatment-tree species combination. The four compost treatments were application of 0, 2, 4, and 6 inches (0, 270, 528, and` 805 cubic yards per acre, equivalent to 0, 513, 1,000, and 1,530 cubic meters per hectare).

The three tree species were Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), noble fir (*Abies procera* Rehd.), and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.). Compost was disked into the soil and seeds were sown in spring 1982. Seedlings were raised according to standard nursery procedures. In fall 1983, the 2 + 0 nursery stock was lifted and stored at 3 °C until spring 1984, when seedlings were outplanted at three sites.

Field. Douglas-fir seedlings were planted with hoedads on the southeast side of Mt. St. Helens in the blast zone on a site (3,000-foot elevation and 35-percent slope) that had been salvage-logged. Planting occurred 4 years after the May 18, 1980, eruption. Tephra, 12 to

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20 inches deep, covered the surface. Roots of planted seedlings did not extend into mineral soil.

Noble fir seedlings were planted near Estacada, OR, on a site with an elevation of 3,800 feet and slope of approximately 20 percent. The site had been logged in 1980, and slash had been hand piled and burned. Considerable brush covered the area. Seedlings were planted with hoedads in mineral soil.

Ponderosa pine seedlings were planted east of the Cascade crest at 3,400 feet elevation, near Leavenworth, WA. The area had been tractor-logged for mixed ponderosa pine and Douglas-fir and broadcast-burned in fall 1983. Slopes were approximately 45 percent. Seedlings were planted with power augers in mineral soil.

The experimental design for all three sites was a randomized complete block (table 1). Each row consisted of seedlings from a single treatment with four treatments in each block. Rows and seedlings within rows were spaced 8 feet apart.

Table 1—*Design of nursery experiment*

Site	Trees/row	Rows/block	Blocks	Total trees
Mt. St. Helens	30	4	5	600
Estacada	12	4	12	576
Leavenworth	24	4	6	576

Table 2—*Height and biomass of conifer seedlings grown for 1 year in nursery beds treated with 2, 4, or 6 inches of compost*

Species	Control (0)	2 inches	4 inches	6 inches	mean
Douglas-fir					
Height (cm)	15.0 b	18.0 a	16.0 b	17.0 b	16.0
Shoot DW (g)	0.78 a	0.81 a	0.72 a	0.88 a	0.80
Root DW (g)	0.39 a	0.32 a	0.31 a	0.35 a	0.34
Root/shoot	0.51 a	0.41 b	0.44 b	0.42 b	0.44
Noble fir					
Height (cm)	9.4 a	9.4 a	9.9 a	9.3 a	9.5
Shoot DW (g)	0.31 a	0.36 a	0.37 a	0.31 a	0.34
Root DW (g)	0.18 a	0.22 a	0.23 a	0.20 a	0.21
Root/shoot	0.56 b	0.62 a	0.65 a	0.68 a	0.63
Ponderosa pine					
Height (cm)	13.0 b	14.0 a	14.0 a	15.0 a	14.0
Shoot DW (g)	0.98 b	1.3 a	1.3 a	1.2 a	1.2
Root DW (g)	0.45 b	0.61 a	0.56 a	0.61 a	0.56
Root/shoot	0.49 a	0.48 a	0.43 a	0.50 a	0.48

Values are the means of 24 samples; values for each row followed by the same letter do not differ significantly (alpha = 0.05)

Measurements and Analyses. Twenty-four seedlings from each compost treatment were measured for height, diameter, and dry weight after 1 and 2 years in the nursery. Nutrient (nitrogen, phosphorus, and potassium) and heavy metal (zinc, copper, lead, nickel, and cadmium) concentrations in roots were measured after 1 year on four pooled samples of 24 seedlings each. Data were analyzed using a fixed-effects one-way ANOVA model of ponderosa pine, Douglas-fir, and noble fir, respectively.

Field measurements of initial seedling height and diameter were made after planting in the spring of 1984. Seedling survival, height, and diameter were measured in the fall of 1984 and 1985. In these cases, a fixed-effect two-way ANOVA model was used for data analysis; compost treatment and blocks were the two factors used.

Results and Discussion

Nursery. Growth. In general, Douglas-fir 1 + 0 seedlings were tallest and ponderosa pine had the greatest biomass (table 2). Ponderosa pine seedlings responded favorably to compost application, with significant treatment effects of height and dry weight. Noble fir and Douglas fir did not show any significant effects of compost treatment on growth parameters. Root collar diameter data are not presented because there were no significant treatment effects.

Mean diameters were 2.4, 1.9, and 2.8 centimeters for Douglas-fir, noble fir, and ponderosa pine, respectively. Growth data from year 2 nursery phase are not presented because treatment effects of 2+0 seedlings in the nursery were similar to results from the outplanting phase.

When seedlings were lifted, average dry weights (in grams) of seedling shoots and roots were: Douglas-fir, 3.6 and 1.7; noble fir, 2.5 and 1.5; ponderosa pine, 7.1 and 1.7. Compost-grown seedlings were generally similar to control seedlings in height, diameter, and shoot and root weights. However, compost-grown Douglas-fir and noble fir were 5 to 30 percent shorter than control seedlings. Compost-grown seedlings also had slightly higher root to shoot ratios than did controls.

Nutrients and metals.
Nutrient concentrations in 1 + 0 seedlings did not differ among species with two exceptions. Potassium levels in noble fir roots were high (1.3 percent) as were nitrogen levels in pine shoots (2.3 percent). Potassium levels were not altered by compost treatment so these data were not included. Average potassium concentrations were 0.64, 1.0, and 0.62 percent for Douglas-fir, noble fir, and ponderosa pine, respectively.

The average root and shoot concentrations for all species combined were 1.5 and 1.9 percent (N), and 0.26 and 0.24 percent (P). A significant increase in nitrogen and phosphorus due to compost application was observed for Douglas-fir and noble fir (table 3). This enhancement in root and foliar phosphorus and in foliar nitrogen was not observed in pine.

Root heavy metal levels (in parts per million) averaged over all species were 4.7 for zinc, 6.0 for copper, 8.1 for lead, 3.4 for nickel, and 1.0 for cadmium. Cadmium and zinc values were as much as six times greater in compost-treated seedlings, but only the cadmium values were significant (table 4).

Other metals (copper, lead, and nickel) did not accumulate above levels found in the control treatment, with one exception. In noble fir, copper levels steadily increased with increasing compost application rate.

There is little information on heavy metal levels in conifer seedlings (4-6). Burton and others (5) found that root growth of Sitka spruce was inhibited at root concentrations greater than

Table 3—*Percent nutrient concentrations in roots and shoots of seedlings grown for 1 year in nursery beds treated with 2, 4, or 6 inches of compost*

Species	Control (0)	2 inches	4 inches	6 inches
Roots				
Douglas-Fir				
Nitrogen	1.4 a	1.6 a	1.6 a	1.5 a
Phosphorus	0.22 c	0.31 a	0.26 a	0.25 b
Noble fir				
Nitrogen	1.3 b	1.5 a	1.5 a	1.5 a
Phosphorus	0.19 b	0.25 a	0.25 a	0.25 a
Ponderosa pine				
Nitrogen	1.3 c	1.6 ab	1.8 a	1.5 b
Phosphorus	0.27 a	0.27 a	0.28 a	0.28 a
Shoots				
Douglas-fir				
Nitrogen	1.5 c	1.7 ab	1.8 a	1.5 b
Phosphorus	0.17 c	0.24 a	0.21 b	0.19 b
Noble fir				
Nitrogen	1.4 b	1.9 a	1.9 a	1.7 a
Phosphorus	0.20 b	0.27 a	0.26 a	0.25 a
Ponderosa pine				
Nitrogen	2.1 a	2.2 a	2.3 a	2.4 a
Phosphorus	0.27 a	0.27 a	0.27 a	0.26 a

Values are means of four tissue analyses, which each were pooled samples from 24 seedlings; values in each row followed by the same letter do not differ significantly (alpha = 0.05).

Table 4—*Heavy metal concentrations in parts per million of roots of seedlings grown for 1 year in nursery beds treated with 2, 4, or 6 inches of compost*

Species	Control (0)		2 inches		4 inches		6 inches		Mean
Douglas-fir									
Zinc	T		0.88	a	1.8	a	3.2	a	2.0
Copper	5.0	a	5.7	a	5.8	a	4.4	a	5.2
Lead	4.4	a	6.2	a	5.2	a	4.4	a	5.0
Nickel	3.5	a	1.6	b	T		1.7	b	2.3
Cadmium	T		0.25	b	0.31	b	0.63	a	0.4
Noble fir									
Zinc	1.2	a	8.6	a	5.9	a	5.6	a	5.3
Copper	3.7	d	5.7	c	6.8	b	7.9	a	6.0
Lead	5.7	a	6.6	a	8.1	a	8.5	a	7.2
Nickel	2.2	a	1.6	a	T		1.7	a	1.9
Cadmium	0.56	b	0.63	b	1.8	a	2.1	a	1.3
Ponderosa pine									
Zinc	4.8	a	11.0	a	5.1	a	T		6.8
Copper	7.2	a	6.1	a	7.3	a	7.0	a	6.9
Lead	12.0	a	11.0	a	9.1	a	16.0	a	12.0
Nickel	6.0	a	5.9	a	5.8	a	6.7	a	6.1
Cadmium	0.50	c	0.13	c	1.3	b	3.5	a	1.4

Values are means of four tissue analyses, which each were pooled samples from 24 seedlings; values for each row followed by the same letter do not differ significantly (alpha = 0.05). T = trace: zinc <0.001; nickel <0.01; cadmium <0.025 ppm.

61 parts per million of cadmium and 228 parts per million of lead. Rolfe and Bazzaz (9) measured inhibition of loblolly pine photosynthesis at similar tissue levels. The values for growth inhibition reported by Burton and others (5) were greater than ten times the cadmium and lead concentrations measured in this study (table 4). Wind River Nursery could accept more composted sludge before toxic levels of these two elements are reached.

Field. After one season's growth in the field, average survival ranged from 97 percent for Douglas-fir to 93 percent for noble fir and 88 percent for Ponderosa pine. For Douglas-fir, field survival of seedlings grown in compost-treated nursery beds was similar to control seedlings, except at the heaviest (6-inch) application rate. Here, year 1 and year 2 survival was reduced from 93 percent (year 1) to 84 percent (year 2, table 5).

For noble fir, survival for compost-grown trees was slightly reduced in year 1, but this effect was not present by year 2. For ponderosa pine, survival effects were complex and seemingly unrelated to compost application rates. Survival was significantly reduced by the 2-inch and 6-inch treatments, but inexplicably, survival in the control and 4-inch treatment was similar.

Douglas-fir height data show that growth in year 1 was much greater than growth in year 2. Reduced second year growth may have been due to low nutrient availability in the tephra. Height increase for the 2-inch treatment was significantly greater than the control treatment.

For noble fir, seedling heights were significantly lower in composted treatments, due to differences developed in the nursery. Percent height increase in compost treatments was significantly greater than controls, suggesting that compost-treated seedlings grew well in the field.

Ponderosa pine seedlings initially were identical in height, but later the composted seedlings were shorter than controls. This trend was carried through the 1985 season. By the end of 1985, height increase of controls exceeded 80 percent whereas that of composted seedlings was only 50 percent. Thus pine may not be suited for treatment with compost.

Conclusions

This study indicates that although initial growth of compost-treated nursery seedlings is improved, probably due to increased nutrient availability,

Table 5—*Two-year height and survival data for 2–0 seedlings grown for 1 year in nursery beds treated with 2, 4, or 6 inches of compost, then outplanted on three sites in Washington and Oregon*

Species	Control (0)	2 inches	4 inches	6 inches
Douglas-fir (Mt. St. Helens, WA)				
Height (cm)				
Spring 84	25.2 a	20.4 b	24.4 b	21.9 b
Fall 84	28.7 a	24.0 b	28.6 a	23.9 b
Fall 85	29.5 a	25.8 b	29.1 a	25.0 b
Total % increase	17.5 b	27.0 a	19.5 ab	14.7 b
Survival (%)				
Fall 84	97.9 a	99.3 a	99.3 a	93.4 b
Fall 85	98.0 a	95.9 a	96.9 a	84.2 b
Noble fir (Estacada, OR)				
Height (cm)				
Spring 84	22.1 a	13.7 b	14.7 b	14.5 b
Fall 84	24.3 a	15.9 b	16.4 b	16.5 b
Fall 85	26.5 a	18.1 b	18.5 b	18.8 b
Total % increase	20.6 b	34.6 a	26.9 a	29.7 a
Survival (%)				
Fall 84	99.2 a	90.9 b	87.2 b	98.3 b
Fall 85	95.4 a	90.2 a	85.9 a	87.3 a
Ponderosa pine (Leavenworth, WA)				
Height (cm)				
Spring 84	17.1 a	18.3 a	17.7 a	16.7 a
Fall 84	23.3 a	20.7 b	21.5 b	19.3 c
Fall 85	30.9 a	27.4 b	27.9 b	25.8 b
Total % increase	81.7 a	49.7 b	58.3 b	54.5 b
Survival (%)				
Fall 84	97.5 a	71.5 c	100.0 a	81.3 b
Fall 85	93.5 a	49.6 c	83.8 a	66.0 b

Seedlings were grown at the Wind River Nursery. Values for each row followed by the same letter do not differ significantly (alpha = 0.05).

subsequent nursery growth seems to be reduced. Nutrient immobilization in the high C/N compost may cause reduced growth. This process is no different than processes that occur after incorporation of traditional organic amendments such as peat, sawdust, or cover crops.

Despite the suspected immobilization effects of compost applications, especially on noble fir and ponderosa pine, the use of compost as an organic amendment appears promising. This is especially true for Douglas-fir, which responded well to compost application as compared to controls. The optimal compost application rate for nursery phase seedlings appears to be either the 2- or 4-inch treatment. Six-inch treatments produced consistently smaller seedlings than did the other compost treatments.

Sludge or composted sawdust/ sludge mixtures should be applied with caution, since this study showed increased cadmium and zinc concentrations in roots of compost-grown trees. Addition of toxic heavy metals should be monitored, because these metals will accumulate in nursery soils. Fortunately, these environmentally hazardous materials often remain in the soil in close association with the applied organic compounds (10). The problem with this soil retention is the possible buildup of these compounds to toxic levels. Lake and others (8) listed annual loading rates of cadmium in Scandinavia at 22 grams per hectare, in the United Kingdom at 167 grams per hectare, and in the United States at 1,250 grams per hectare.

Rather than discussing annual application rates, Bicklehaupt (2) referred to cumulative levels for several different heavy metals. Cadmium levels should not exceed 20 kilograms per hectare, whereas zinc levels should not exceed 1,000 kilograms per hectare for soils with high cation exchange capacities. In soils with lower cation exchange capacities, such as sandy soils or soils that are low in organics, these maximum levels are cut by a factor of four. It therefore appears evident that use of sludge or composted sludge compounds in forest nurseries for organic inputs will require careful monitoring of soil and tissue levels so that toxic levels and seedling growth inhibition do not occur.

Literature Cited

1. Berry, C.R. Growth and heavy metal accumulation in pine seedlings grown in sewage sludge. Journal of Environmental Quality 14:415-419; 1985.
2. Bickelhaupt, D.H. Potential hazards of some organic wastes that may be used in nurseries. Proceedings of North American Forest Tree Nursery Soils Workshop; Syracuse, NY; July 28-August 1, 1980: 166-173.
3. Bledsoe, C.S. Composted sludge as a plant growth medium. In: Bledsoe, C.S., ed. Municipal sludge application to Pacific Northwest forest lands. Contr. 41. Seattle: University of Washington Institute of Forest Resources, 1981:87-91.
4. Bledsoe, C.S.; Zasoski, R.J. Seedling physiology of eight tree species grown in sludge-amended soils. In: C.S. Bledsoe, ed. Municipal sludge application to Pacific Northwest forest lands. Contr. 41. Seattle: University of Washington Institute of Forest Resources, 1981: 93-100.
5. Burton, K.W.; Morgan, E.; Roig, A. The influence of heavy metals upon the growth of sitka-spruce in South Wales forests. II. Greenhouse experiments. Plant and Soil 78:271-282; 1984.
6. Burton, K.W.; Morgan, E.; Roig, A. Interactive effects of cadmium, copper and nickel on the growth of Sitka spruce and studies of metal uptake from nutrient solutions. New Phytology 103:549-557; 1986.
7. Davey, C.B.; Krause, H.H. Functions and maintenance of organic matter in forest nursery soils. Proceedings, North American Forest Tree Nursery Soils Workshop, Syracuse, NY, July 28-August 1, 1980: 130-165.
8. Lake, D.L.; Kirk, P.W.W.; Lester, J. N. Fractionation, characterization, and speciation of heavy metals in sewage sludge and sludge-amended soils: review. Journal of Environmental Quality 13:175-183; 1984.
9. Rolfe, G.L.; Bazzaz, F.A. Effect of lead contamination on transpiration and photosynthesis of loblolly pine and autumn olive. Forest Science 21:33-35; 1975.
10. Zasoski, R.J. Heavy metal mobility in sludge-amended soils. In: Bledsoe, C.S., ed. Municipal sludge application to Pacific Northwest forest lands. Contr. 41. Seattle: University of Washington Institute of Forest Resources; 1981: 67-72.

Damage and Mortality to Pecan *(Carya illinoensis* (Wangenh.) K. Koch) Seedlings by Subterranean Termites *(Reticulitermes flavipes* (Kollar)) in an Oklahoma Forest Nursery

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*Termite injury to pecan (*Carya illinoensis *(Wangenh.) K. Koch) was characterized by yellow, necrotic foliage. Tap roots of infested seedlings exhibited one or more small round or oval holes 4 to 8 centimeters (1.6 to 3 inches) below the soil surface -- some were tunneled so badly that only a thin shell remained. Sampling revealed that 47.5 percent of the seedlings showed foliar symptoms and 2.5 percent of the seedlings were dead.* Tree Planters' Notes 38(2):28-30; 1987.

Subterranean termites (*Reticulitermes* spp.) destroy more wood in use in the United States than does any other insect pest (2). *Reticulitermes flavipes* (Kollar) is the most common species in the eastern and southern United States, while *R. tibialis* Banks is important in the West (4).

Although subterranean termite damage to wooden structures is well documented, damage to living trees occurs infrequently in the United States and is less well known. St. George (6) reported damage by *R. flavipes* to living shrubs in Washington, DC. Edelson and Hyche (3) mentioned termite damage to sycamore and oak seedlings in Alabama. Payne (4, 5) stated that pecan nursery stock and small trees are sometimes killed by termites feeding, but he cited no specific cases. Herein, we describe a case of termite damage to nursery-grown pecan seedlings in Oklahoma.

Nursery Setting

The observation was made in a nursery near Washington (Cleveland County) in central Oklahoma. A single bed 213 meters (700 feet) long was planted to pecan, *Carya illinoensis* (Wangenh.) K. Koch. The seed were planted in fall 1983, three rows per bed, and 12 seeds per linear foot (0.3 meter). No sawdust or other mulch was added. Nitrogen was applied at the rate of 90 kilograms per hectare (80 pounds per acre) split among six applications distributed over the growing season.

Shortleaf pine (*Pinus echinata* Mill). was grown during the previous season (1983-84). A bed of bur oak seedlings was planted on one side of the pecan bed. A cover crop of Sudan grass and wheat was planted in a strip 4.6 meters (15 feet) wide between the pecan planting and an arborvitae windbreak.

Description and Extent of Injury

Damage was first observed in mid-July 1984. Earliest symptoms on affected seedlings were yellowing of foliage and leaf necrosis, followed by browning and drying of leaves, and subsequent mortality. A sample of affected seedlings was lifted and examined, revealing tunnels in the roots. Termites (*R. flavipes*) were found in the tunnels of some roots, while other tunnels (fig. 1) contained only fecal material.

On July 27, the nursery bed was sampled for extent of injury. The sample included thirteen 1.2-meter (4-foot) linear plots selected at random. Sample plots contained 122 seedlings that were examined for foliar symptoms and mortality. The sampling revealed that 47.5 percent of the seedlings showed foliar symptoms of leaf necrosis, and 2.5

Figure 1—*Pecan seedlings injured by termites.* **(A)** *Tap root of seedling dissected to expose the tunneling termites.* **(B)** *Entrance holes made in sides of tap roots.* **(C)** *Tap roots tunneled so badly that only thin shells remain.*

percent of the seedlings were dead. Mortality was spotty throughout the nursery bed, with mortality in some pockets greatly exceeding the average of 2.5 percent. Damage was heaviest at the east end of the nursery bed.

A smaller sample of affected seedlings was randomly selected for excavation and examined for root tunneling. Six (46.2 percent) of 13 living seedlings excavated with necrotic foliage exhibited galleries in the roots. Eleven (78.5 percent) of 14 dead seedlings had root galleries.

Infested seedlings typically exhibited one or more small, nearly round or oval entrance holes in the tap roots (fig. 1B). Entrance holes 1 to 3 millimeters (0.04 to 1.14 inch) in diameter were present from just below the root collar down to a depth of 10 centimeters (3.9 inches), but most holes occurred from 4 to 8 centimeters (1.6 to 3.2 inches) below the soil surface.

Dissection of infested roots revealed galleries extending in both directions from the entrance holes, from about the root collar down to depths of 14 centimeters (5.5 inches). A few galleries extended slightly above the root collar, but were not visible externally. The tap roots of some seedlings were tunneled so badly that only a thin shell or bark remained (fig. 1C). Seedlings pulled from the ground commonly broke at these weakened sites, leaving part of the tap root in the soil.

After the damage was discovered and identified in late July, the nursery bed was treated for control of the termites. The bed was treated with Lorsban 4E (41 percent) (1) at the rate of 43 grams active ingredient per 93 square meters (1.5 ounces a.i. per 1,000 square feet) and irrigated. No further damage was observed. No further samples were taken.

Discussion and Conclusion

Termites are known to establish in soil where there is decaying wood, sawdust, and other organic matter suitable for food. When this happens, termites can successfully invade living plants, especially when the plants have injuries or are weakened from other causes. Some of the pecan seedlings may have been weakened by causes other than termites because only about half of the lifted seedlings with foliar symptoms exhibited termite entrance holes and tunnels. However, we found no pathogen or other obvious adverse factors. No mulch or other organic matter was added to the nursery soil, nor were there any wood stakes, form boards, etc., placed in the nursery.

Because the bed of pecan seedlings was only 4.6 meters (15 feet) from the arborvitae windbreak, it seems most likely that this was the source of infestation. In all likelihood, the termites tunneled through the soil in search of food, reaching the nursery bed with the pecan seedlings.

Because many of the damaged seedlings are vacated after some degree of tunneling, the entrance holes and gallery within the tap roots can easily lead to the mistaken diagnosis of insect borers. Therefore, the description of injury presented here can help nursery workers and others to correctly identify the cause of injury and apply appropriate treatment. Moreover, good sanitation and preventive treatment of small amounts of soil insecticide incorporated into beds could help prevent or minimize termite infestations in nurseries.

Literature Cited

1. Beal, R.H. New materials for termite control. Pest Control 48:46-48, 50, 52, 54; 1980.
2. Beal, R.H.; Mauldin, J.K.; Jones, S.C. Subterranean termites-Their prevention and control in buildings. Home Garden Bull. 64. Washington, DC; U.S. Department of Agriculture; 1983. 36 p.
3. Edelson, J.V.; Hyche, L.L. Insects associated with injury to deciduous tree seedlings growing in forest tree nurseries in Alabama. Journal of Economic Entomology 73:698-701; 1980.
4. Payne, J.A. Termites. In: Ellis, H.C.; Bertrand, P.F.; Crocker, T.F., eds. Pecan growers handbook. MP 176. Athens, GA: University of Georgia, Cooperative Extension Service; 1984. p. 32.
5. Payne, J.A.; Malstrom, H.L.; Ken-Knight, G.E. Insect pests and diseases of the pecan. ARM-S-5. New Orleans, LA: U.S. Department of Agriculture, Agricultural Research Service: 1979. 43 p.
6. St. George, R.A. Protecting yews from termite damage. Pest Control 25:38, 40, 42, 44; 1957.